Effects on Development of Immature Mexican Corn Rootworm (Coleoptera: Chrysomelidae)

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ABSTRACT Development of immature Mexican corn rootworm, *Diabrotica virgifera zeae* Krysan & Smith, was investigated at 8 temperatures ranging from 15 to 33°C. Development to adult was only completed in the range from 15 to 30°C; larvae failed to complete the 3rd instar at 31.5 and 33°C. Development from hatch to adult emergence was fastest at 30°C (≈25 d), and slowest at 15°C (≈105 d). Developmental times, from hatch to adult emergence, differed for males and females, males emerged before females. A pooled thermal threshold of 10.3°C was estimated for immature development. Development from hatch to adult emergence was estimated to take 473 DD.

KEY WORDS *Diabrotica virgifera zeae,* degree-days, linear model

THE MEXICAN CORN rootworm, *Diabrotica virgifera zeae* Krysan & Smith, is a univoltine pest of corn, *Zea mays* (L.), from Oklahoma into Central America. This corn rootworm was first reported to be an economic pest in south central Texas in 1977 (Stewart 1977). It was not differentiated from the western corn rootworm, *D. virgifera* LeConte, until 1980 when it was described as a subspecies, *D. virgifera zeae* Krysan & Smith (Krysan et al. 1980).

To date, there has been no investigation of the thermal requirements for development of this pest. Branson et al. (1982) did not observe differences in the rate of development between Mexican corn rootworm in central Mexico and *D. v. virgifera* in the U.S. corn belt, except that all events happened ≈1 mo later in Mexico. The study reported here was initiated to provide a quantitative description of the effects of temperature on immature Mexican corn rootworm development and to compare and contrast its thermal requirements with those of the closely related western corn rootworm.

Materials and Methods

Mexican corn rootworm eggs were obtained from adults collected near Temple (Bell County), TX, during the summer of 1995 and 1996. Adults were maintained at 25–27°C and fed corn ears, squash, and an artificial diet (Jackson 1986). Our methods paralleled those of Jackson and Elliott (1988) with the western corn rootworm, using the same maize variety (B37× H84, F_2) to facilitate comparisons between the 2 species. Eggs were stored in soil at room temperature for 3–6 mo, washed from the soil, incubated at 25 ± 1°C on moist blotter paper, and checked daily for hatch. Newly hatched 1st instars were placed individually on a root of a 3-d-old corn seedling in a capped 15-ml plastic container with a 1-cm^2 sheet of moist, sterilized blotter paper on the bottom. Containers were prepared and placed at each experimental temperature (15, 18, 21, 25, 27, 30,31.5, and 33°C all ± 0.5°C). At 24-h intervals, the stage of each insect was determined, the container ventilated, the corn seedling replaced, and the moisture of the blotter paper adjusted to near saturation. This schedule ensured that an excess of fresh corn tissue was available to each larva at all times. When a 3rd instar was 3 d old, it was placed in a 30-ml plastic container. These pupation containers held a corn seedling placed on blotter paper, and 10 g of soil (20% moisture by weight) for constructing a pupal cell. The corn seedling was changed daily until the larva constructed a pupal cell. Once a pupal cell was formed, the corn seedling was discarded and soil moisture was maintained at ≈20% by weight. Daily inspections were made to determine insect development, ventilate the containers, and adjust soil moisture as needed. Only insects that completed development to the adult stage were used in these analyses.

An analysis of variance (ANOVA) was used to examine the effects of temperature on developmental times and adult head capsule widths. A significance level of $P \leq 0.05$ was used for all tests. The rate of development was calculated as the reciprocal of the mean time, in days, for each life stage. Developmental threshold temperatures (t_b) for each life stage were estimated using the x-intercept method, $t_b = |a|/b$, where a and b are estimates of the y intercept and slope, respectively (Arnold 1959). Degree-day estimations for development of each life stage were calculated using the formula $DD = T\ (t - t_b)$, where T is the mean number of days for development at a constant temperature (t), and t_b is the lower threshold (Arnold 1960). Degree-days were calculated using

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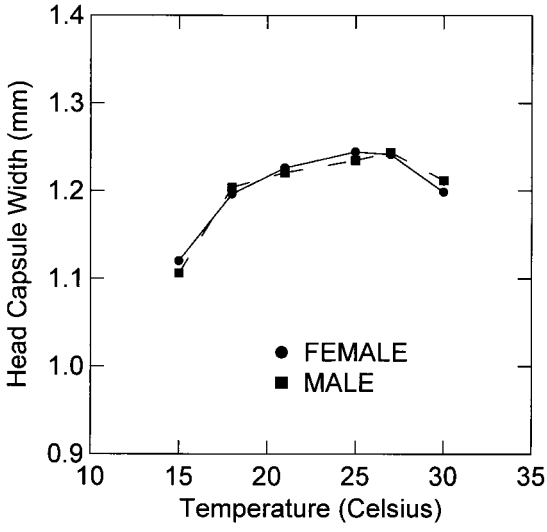

Fig. 1. Effect of constant temperature on adult head capsule width.

data from the 15–27°C ranges, where the relationship between temperature and developmental rate was approximately linear. Degree-days estimates for each temperature were averaged to obtain the mean degree-day requirement for development. A common estimate of t_b was used for all degree-day estimates and was calculated as the average of t_b for development from hatch to adult emergence for both sexes.

Results and Discussion

Development from egg hatch to adult occurred only in the range of 15–30°C. Larvae failed to progress beyond the 3rd stadium at 31.5 and 33°C, and survival of both sexes declined above 27°C. A two-way ANOVA on adult head capsule width versus sex and temperature showed that temperature had a significant effect ($F = 44.5886$; df = 5, 428; $P = 0.0001$) on head capsule width. However, sex and its interaction with temperature did not have a significant effect on adult head capsule width ($F = 0.4260$; df = 1, 428; $P = 0.5143$; $F = 1.0820$; df = 5, 428; $P = 0.3696$). These data show that, unlike the western corn rootworm (Jackson and Elliott 1988), there are no significant differences between the sexes in terms of their development in relation to temperature. Head capsule widths were narrowest at 15°C (Fig. 1), but were otherwise fairly consistent across temperatures, fastest development occurred between 21 and 27°C. In contrast, the best development range for western corn rootworm survival and development is between 21 and 30°C (Jackson and Elliott 1988). Deformed adults were quite rare in our study, only 3 of 440 adults had deformed elytra. There was no apparent association between sex or temperature and the occurrence of these deformities.

There was a decrease in developmental time with increasing temperature for most life stages (Table 1). Second-instar males were the exception, development at 30°C taking slightly longer than at 27°C. Like the northern and western corn rootworms, there is a small period between adult emergence and adult escape from the pupal cell (Jackson and Elliott 1988, Woodson and Jackson 1996). The length of this period was influenced by temperature as in the other stadia but, unlike those, was longer above 27°C (Table 1). Temperature had a highly significant effect on the developmental time of all life stages (Table 2). Only the pupal stage had a significant interaction between sex and temperature, and this was caused by the difference in developmental rates between females and males at 15°C.

The proportion of time spent in each stadium relative to the total immature development time, from hatch to adult emergence, as temperature increased

Table 1. Mean development time (days) ± SEM required for *D. virgifera zeae* at 6 constant temperatures

Period–Sex	15°C	18°C	21°C	25°C	27°C	30°C
Male (*n*)	19	45	57	39	32	37
Female (*n*)	20	41	58	37	31	24
I instar male	17.47 ± 0.32	10.58 ± 0.21	7.61 ± 0.17	5.51 ± 0.13	4.97 ± 0.08	4.73 ± 0.15
I instar female	18.00 ± 0.94	11.46 ± 0.35	8.00 ± 0.13	5.57 ± 0.11	5.52 ± 0.15	4.92 ± 0.12
II instar male	16.11 ± 0.40	9.38 ± 0.20	5.93 ± 0.13	4.31 ± 0.13	3.81 ± 0.12	3.86 ± 0.08
II instar female	16.65 ± 0.41	10.05 ± 0.19	6.48 ± 0.13	4.54 ± 0.13	4.16 ± 0.17	4.13 ± 0.13
III instar male	39.05 ± 0.70	25.00 ± 0.52	15.96 ± 0.29	11.36 ± 0.30	10.66 ± 0.38	9.70 ± 0.25
III instar female	39.95 ± 0.70	25.59 ± 0.34	17.29 ± 0.42	11.92 ± 0.37	9.97 ± 0.21	9.92 ± 0.32
Pupal Male	28.16 ± 0.28	16.42 ± 0.11	10.96 ± 0.08	7.05 ± 0.06	6.09 ± 0.08	5.62 ± 0.08
Pupal Female	29.80 ± 0.59	16.85 ± 0.10	11.43 ± 0.10	7.19 ± 0.08	6.26 ± 0.08	5.79 ± 0.09
Adult emergence to escape: male	1.95 ± 0.34	1.64 ± 0.15	1.11 ± 0.11	0.92 ± 0.12	0.84 ± 0.10	1.05 ± 0.09
Adult emergence to escape: female	2.20 ± 0.37	1.73 ± 0.19	1.26 ± 0.11	1.08 ± 0.13	0.84 ± 0.12	1.13 ± 0.13
Hatch to adult emergence: male	100.79 ± 1.36	61.38 ± 0.80	40.47 ± 0.42	28.23 ± 0.36	25.53 ± 0.38	23.92 ± .28
Hatch to adult emergence: female	104.40 ± 1.35	63.95 ± 0.64	43.21 ± 0.54	29.22 ± 0.40	25.90 ± 0.35	24.75 ± .31
Hatch to adult escape: male	102.74 ± 1.45	63.02 ± 0.79	41.58 ± 0.42	29.15 ± 0.37	26.38 ± 0.39	24.97 ± .28
Hatch to adult escape: female	106.60 ± 1.42	65.68 ± 0.61	44.47 ± 0.53	30.30 ± 0.38	26.74 ± 0.33	25.88 ± .34

Table 2. ANOVA of developmental times for *D. virgifera zeae*

Stage	Source	df	MS	F	P
1st instar	Temp	5	1,199.37	350.62	<0.00
	Sex	1	18.14	5.30	0.02
	Temp × Sex	428	1.67	0.49	0.79
2nd instar	Temp	5	1,145.33	1,055.25	<0.00
	Sex	1	18.47	17.02	<0.00
	Temp × Sex	428	0.60	0.56	0.73
3rd instar	Temp	5	6,691.27	1,133.18	<0.00
	Sex	1	22.74	3.85	0.05
	Temp × Sex	428	8.87	1.50	0.19
Pupa	Temp	5	3,872.83	5,621.40	<0.00
	Sex	1	24.59	35.69	<0.00
	Temp × Sex	428	3.61	5.24	<0.00
Hatch to adult emergence	Temp	5	45,093.03	3,435.79	<0.00
	Sex	1	334.34	25.47	<0.00
	Temp × Sex	428	25.49	1.94	0.09
Hatch to adult escape	Temp	5	40,364.00	2,881.25	<0.00
	Sex	1	281.32	20.08	<0.00
	Temp × Sex	428	18.94	1.35	0.24

depended upon the life stage (Fig 2.). The proportion of time taken by the 1st stadium significantly (F = 10.0343; df = 5, 434; P = 0.0001) increased with increasing temperature. For the 2nd stadium it was greater (F = 4.3045; df = 5, 434; P = 0.0008) at the extremes than at the midrange temperatures, and less than the 1st stadium, unlike in the northern corn rootworm (Woodson and Jackson 1996). The proportion of time taken by the 3rd stadium was similar across all temperatures; no significant differences were detected (F = 1.4967; df = 5, 434; P = 0.1896). For the pupal stadium this proportion declined significantly (F = 65.5289; df = 5, 434; P = 0.0001) with increasing temperature. Averaged across all temperatures, the 1st stadium took 18% of the immature time, whereas the 2nd, 3rd, and pupal stadia took 16, 40, and 26% of the immature time, respectively. These results are similar to those of Jackson and Elliott (1988) for the western corn rootworm, who found the proportion of total development time to be 18, 16, 36, and 30% for the 1st, 2nd, 3rd, and pupal stadia, respectively.

The dependence between developmental rate and temperature for each sex, developmental stage, and for the periods of hatch to adult emergence and hatch to adult escape, were approximately linear over the temperature range of this investigation. Linear regressions over these temperatures yielded coefficients of determination from 0.96 to 0.99 (Table 3). Estimates of t_b were generally similar for both sexes and all developmental stages except for the pupal stage of both sexes (Table 3). Averaged over all stadia and both sexes, a pooled t_b was estimated to be 10.3°C. This is considerably higher than the 9°C that Jackson and Elliott (1988) estimated for the western corn rootworm. The reason for such a dramatic difference in t_b

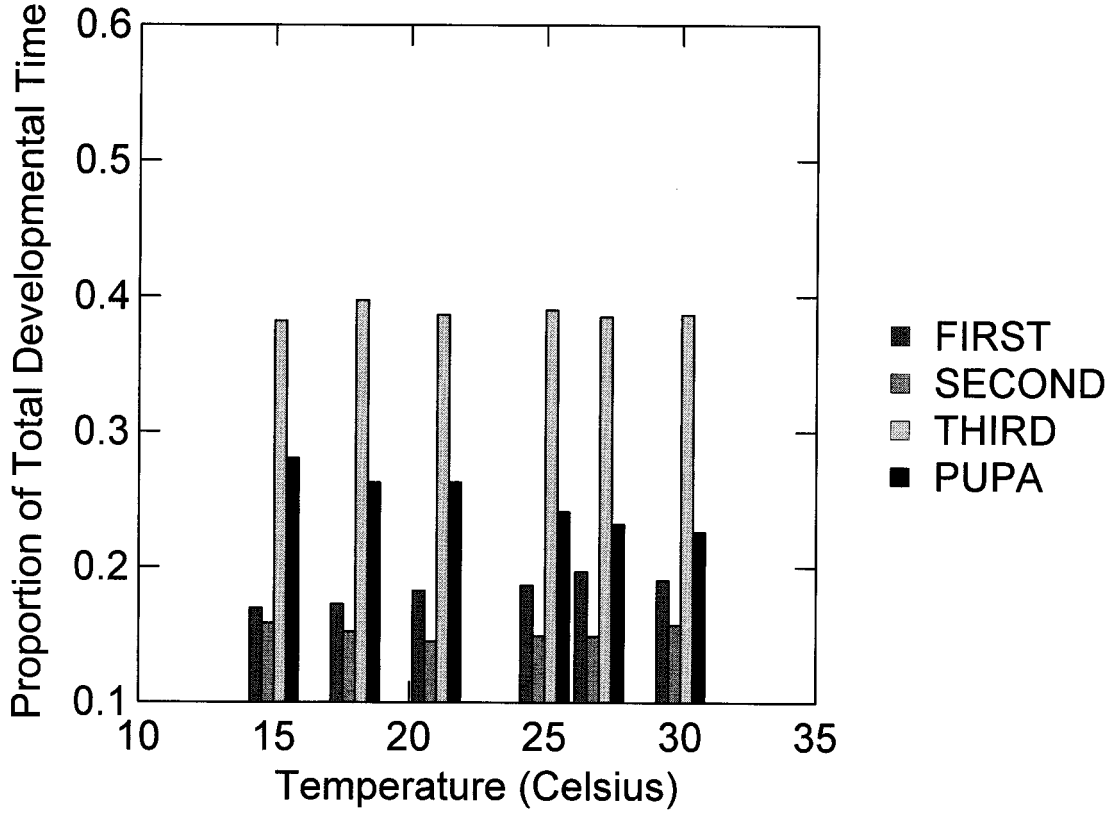

Fig. 2. Effect of constant temperature on the proportion of developmental time in each immature stage.

Table 3. Estimated lower development thresholds and developmental time in and degree-days for *D. virgifera zeae*

Stage	Threshold equation	N (temp)	R^2	T_b, °C	DD ± SEM
		Females			
1st instar	$y = -0.0938 + 0.0103x$	6	0.97	9.11	88.21 ± 2.24
2nd instar	$y = -0.1327 + 0.0133x$	6	0.96	9.98	73.75 ± 2.42
3rd instar	$y = -0.0585 + 0.0056x$	6	0.97	10.45	184.47 ± 4.82
Pupa	$y = -0.1166 + 0.0099x$	6	0.99	11.78	119.41 ± 5.72
Hatch to adult emergence	$y = -0.0234 + 0.0022x$	6	0.98	10.63	465.84 ± 11.88
Hatch to adult escape	$y = -0.0217 + 0.0021x$	6	0.97	10.33	481.66 ± 11.84
		Males			
1st instar	$y = -0.0993 + 0.0108x$	6	0.98	9.19	83.71 ± 1.91
2nd instar	$y = -0.1443 + 0.0144x$	6	0.95	10.02	69.08 ± 2.57
3rd instar	$y = -0.0548 + 0.0055x$	6	0.98	9.96	180.49 ± 4.28
Pupa	$y = -0.1182 + 0.0102x$	6	0.99	11.59	115.38 ± 5.03
Hatch to adult emergence	$y = -0.0235 + 0.0023x$	6	0.98	10.22	448.66 ± 10.93
Hatch to adult escape	$y = -0.0219 + 0.0022x$	6	0.98	9.95	463.75 ± 10.89

Base developmental threshold temperature = 10.3°C.

is probably linked to seasonal cropping patterns or host plant availability. Emergence of western corn rootworm males precedes female emergence by several days (Kuhlman 1970, Branson 1987, Jackson and Elliott 1988); however, Mexican corn rootworm males emerge only a day or 2 before female emergence. Our data (Table 1) show few differences between males and females except at the lower temperatures, where the males emerged 2–3 d ahead of the females.

Accumulated degree-days (base 10.3°C) for completion of each life stage are presented in Table 3. Immature Mexican corn rootworm require more time to develop than immature western corn rootworms. Jackson and Elliott (1988) found that western corn rootworms required ≈434 DD, from hatch to adult escape, whereas we found that it took, on average, ≈473 DD for the Mexican corn rootworm to complete the same developmental period. Data for egg hatch requirements are unknown, and given the differences between Mexican corn rootworm and western corn rootworm larval development found in this study, it seems unlikely that western corn rootworm data will be sufficient for accurate prediction of Mexican corn rootworm field events. Another complicating factor is that the Mexican corn rootworm egg hatch may be as much influenced by soil moisture as soil temperature. Krysan et al. (1977) found *D. v. virgifera* to be more susceptible to desiccation than Mexican corn rootworm, and that Mexican corn rootworm eggs remain in a state of dry quiescence postdiapause until adequate moisture was in contact with the eggs to initiate hatch. Branson et al. (1982) reported finding all life stages in central Mexico depending on the availability of soil moisture; evidently soil moisture of >20% was adequate for embryonic development.

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References Cited

Arnold, C. Y. 1959. The determination and significance of the base temperature in a linear heat unit system. J. Am. Soc. Hortic. Sci. 74: 430–445.

Arnold, C. Y. 1960. Maximum-minimum temperature as a basis for computing heat units. J. Am. Soc. Hortic. Sci. 76: 682–692.

Branson, T. F. 1987. The contribution of prehatch and posthatch development to protandry in the chrysomelid, *Diabrotica virgifera virgifera.* Entomol. Exp. Appl. 43: 205–208.

Branson, T. F., J. R. Reyes, and H. M. Valdés. 1982. Field biology of Mexican corn rootworm, *Diabrotica virgifera zeae* (Coleoptera: Chrysomelidae), in central Mexico. Environ. Entomol. 11: 1078–1083.

Jackson, J. J. 1986. Rearing and handling of *Diabrotica virgifera* and *Diabrotica undecimpunctata howardi*, pp. 25–47. *In* J. L. Krysan and T. A. Miller [eds.], Methods for the study of pest *Diabrotica.* Springer, New York.

Jackson, J. J., and N. E. Elliott. 1988. Temperature-dependent development of immature stages of the western corn rootworm, *Diabrotic virgifera virgifera* (Coleoptera: Chrysomelidae). Environ. Entomol. 17: 166–171.

Krysan, J. L., R. F. Smith, T. F. Branson, and P. L. Guss. 1980. A new species of *Diabrotica virgifera* (Coleoptera: Chrysomelidae): description, distribution, and sexual compatibility. Ann. Entomol. Soc. Am. 73: 123–130.

Kuhlman, D. E. 1970. Bionomics of *Diabrotica logicornis* (Say) and *Diabrotica virgifera* LeConte (Coleoptera: Chrysomelidae). Ph.D. dissertation, University of Illinois, Urbana.

Stewart, J. W. 1977. Western corn rootworm in corn. Wintergarden Insect report 6–8. Texas Agricultural Extension Service, Uvalde, TX.

Woodson, W. D., and J. J. Jackson. 1996. Developmental rate as a function of temperature in Northern corn rootworm (Coleoptera: Chrysomelidae). Ann. Entomol. Soc. Am. 89: 226–230.

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